DEBRIS-COVERED GLACIERS ON MARS: INVESTIGATING THE RELATIONSHIP BETWEEN SURFACE RIDGES AND INTERNAL STRUCTURE THROUGH COMPARISON TO EARTH ANALOGS.

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Introduction: It is widely believed that the lobate debris aprons (LDAs) in the mid-latitudes of Mars are examples of debris-covered glaciers (DCGs): massive ice deposits covered by a thin (<10 m) layer of debris [1-3]. LDA are thought to be composed predominantly of glacial ice capped by a debris layer ~10 m thick; however, their internal structure remains unknown. If the internal structure of DCGs can be related to the geologic and climate histories of the regions in which they were formed, then LDA morphology can provide insight into LDA history and could constrain the time and duration of LDA formation, in addition to helping shape our understanding of martian climate history as a whole.

On Earth and Mars, many DCGs exhibit arcuate ridges transverse to the flow direction. There exists some evidence linking internal structure in DCGs with surface microtopography [4][5][6]. Notably, a study of Mullin's DCG in the McMurdo Dry Valleys, discovered a relationship between glacial surface ridges and englacial debris layers [6]. A developed understanding of the relationship between debris-covered glacier surface topography and interior structure could be highly useful for planetary scientists -- – there exists an abundance of martian topography data and imagery, but detecting internal structure in martian DCGs remains difficult. A better understanding of the relationship between debris bands, compressional stresses, and debris-covered glacier microtopography will augment understanding of formational environments and mechanisms for martian LDAs Furthering our understanding of the relationship between debris bands, compressional stresses, and debris-covered glacier microtopography will augment our understanding of formational environments and mechanisms for martian LDAs.

Methods: In order to better understand relationships between DCG surface morphology and internal debris bands, we conducted a geophysical survey of the Galena Creek Rock Glacier, WY. Time-domain electromagnetic (TDEM) surveys were completed in 27 locations across the glacier; over 3400 m of ground-penetrating radar (GPR) surveys were performed across 11 tracks. Geomorphic analysis by surface observation and photogrammetry, including examination of a cirque-based thermokarst, was used to guide and complement geophysical sounding methods. TDEM inversions were completed in Geomodel. GPR processing and analyses were completed in EKKO_Project 2 and MATLAB.

Observations: *Geological Analysis:* Very clean ice below a 1 m thick layer of debris was directly observed on the walls of a 40 m diameter thermokarst pond near the accumulation zone. An englacial debris band 0.7 m thick dipping 30^{o} intersected the wall of the pond. A 0.8-m deep, 1-m diameter, subcircular depression occurred at the intersection of the debris band with the surface at the rim of the thermokarst. Ridges and furrows occur at varying ridge-to-ridge wavelengths at different locations on the glacier: 43 m in a small cirque on the upper glacier, 9 m in the large cirque at the upper glacier, and 40 m in the lower glacier region.

TDEM: TDEM inversions were consistent with a resistive layer 1.67 m thick overlying a less resistive layer 24-75 m thick.

GPR: The 50 and 100 MHz lines closest to the accumulation zone of the glacier transected six surface ridges (Figure 1). The GPR data shows a series of reflectors that slope upwards towards the surface. Ridges occur at the projected reflector/surface intersection. Hyperbolae analysis yields a value of 0.152 m/ns for the velocity of the radar wave in the subsurface.

Analysis: The subsurface radar velocity in the upper cirque (0.150 m/ns) is consistent with temperate ice. Based on the shape of the dipping reflectors, and observations at the thermokarst, it is likely that the dipping reflectors represent debris bands. Thus, the upper glacier appears to be composed of clean, massive ice with planes of englacial debris within. The reflectors dip up-glacier, and their projections intersect the surface at angles from 15-35^{o}. The intersection angle appears to increase for debris layers that are further down-glacier, possibly due to increased deformation due to differential stresses applied to the debris band. (i.e. increased loading with depth creates an increasingly concave debris-layer shape as material accumulates on top of the glacier). Surface ridges correlate with the intersection of debris layers and the surface.

Implications for Mars: It is possible that debris layer interactions have shaped similar compressional ridges on martian LDAs. This work found a subsurface radar velocity consistent with clean ice (analogous to LDA purity), but debris bands are also present. If the relationship between ridge topography and debris bands were understood in more detail, constraints on martian geologic activity and possibly even climate cycles during LDA formation could be obtained. This would be an important step towards understanding the time scales over which LDA are formed, and possibly provide constraints on the protective debris-layer emplacement process.

Limitations: Martian LDA ridge features occur on drastically different scales than what was observed at GCRG. It is unknown whether debris layer-ridge/furrow interactions could scale to ~10 times what was studied here. Martian DCG's are also much colder than GCRG. Modeling will attempt to address these problems in future work.

Conclusions: At GCRG, debris bands imaged in GPR intersect the glacier suface at ridges observable in photogrammetric DEMs. Because of the clear relation between surface ridges and linear features in GPR, as well as the information we have on the nature of the debris bands within GCRG, we believe it would make a good candidate for flow modeling.

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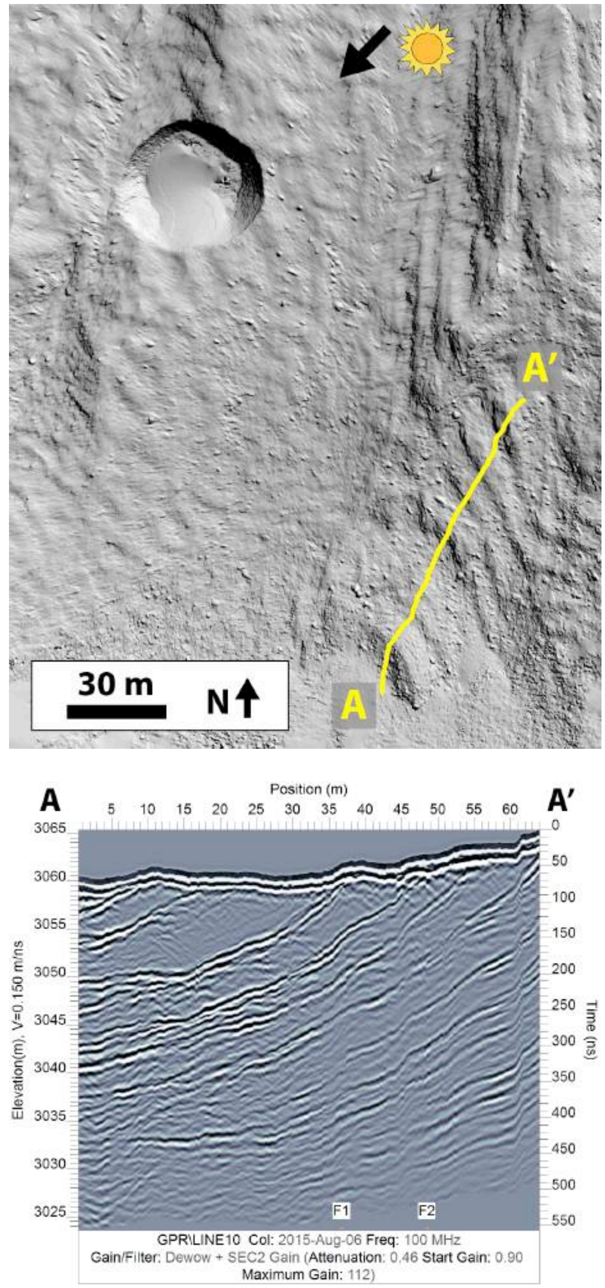

Figure 1: Ground-Penetrating Radar (GPR) data collected from Galena Creek Rock Glacier, Wyoming USA. *Top:* DEM of upper glacier, near accumulation zone, created using photogrammetry. Note the thermokarst in the upper left. The yellow line marks the GPR track. *Bottom:* GPR data over the ridges along the track marked above. The linear features are interpreted as debris bands, and ridges are observed where they intersect the surface. [Figure courtesy of E.I. Petersen]